Irrigation Scheduling and Row Configurations for Corn in the Southeastern Coastal Plain

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ABSTRACT

POOR rainfall distribution and soil physical conditions such as high soil strength and low water-holding capacity often limit production of crops such as corn *(Zea mays* L.) in the Southeastern Coastal Plain. To produce high and profitable corn yields in this region, proper water, nutrient, and cultural practices must be implemented. This study was conducted to determine whether different irrigation scheduling methods, row configurations, plant populations, or fertilization programs could improve energy or water efficiency or improve corn yields. Nonirrigated production was compared to irrigated production where irrigation was scheduled by two methods. In 1980 irrigation was initiated when soil-water tensions reached either 25 (TENS 25) or 50 kPa (TENS 50) in the 30- to 60-cm depth range. In 1981 and 1982, irrigation was initiated when soil-water tension in this depth range reached 25 kPa or when indicated by a computer-based water balance (CBWB). Irrigated treatments produced an overall average corn yield of 12.08 Mg/ha while the nonirrigated treatment produced an average yield of 6.70 Mg/ha. There were no significant differences in corn yield between scheduling methods, but, compared to nonirrigated treatments, irrigation increased yields 150, 161, and 8 percent in 1980, 1981, and 1982, respectively. The CBWB consistently overestimated available soil-water volume both years, particularly during pollination and early grain fill periods when evapotranspiration was high. Row configurations evaluated included single rows spaced 96 cm apart and twin rows spaced 30 cm apart on 96-cm centers. The twin-row configuration significantly increased corn grain yield each year by an average of 0.64 Mg/ha presumably because of reduced intrarow competition for water and increased light interception.

INTRODUCTION

Irrigation in the humid Southeast has increased rapidly during the past few years, particularly in the Coastal Plain region where coarse-textured soils have low water-holding capacities. Although annual rainfall normally equals or exceeds evapotranspiration (ET), seasonal rainfall is not adequately distributed during the crop growing season. In many cases, if compacted soil horizons are not disrupted by deep tillage, plant rooting is limited to shallow soil depths (20 to 45 cm). Crops suffer from drought stress after 5 to 7 days without rainfall unless irrigation is provided (Lambert, 1980). To justify the investment in irrigation equipment, landowners are planting more land area to water responsive crops such as corn *(Zea mays* L.) and are growing multiple crops. Changes in cultural practices and improvements in water and nutrient management are needed to stabilize or improve yields and to offset increased production costs.

Several irrigation scheduling methods have been suggested for the humid region, but few have been accepted by irrigation managers in the southeastern U.S. The use of soil-water potential (tensiometers) to manage irrigation is widely recognized and recommended (Bruce et al., 1980; Rhoads, 1982), but this technique is not being widely used (Lambert, 1980). Those who do not use tensiometers usually cite the following reasons: time and labor requirements; soil variability; difficulty in converting from soil-water potential to water volume; and sensor cost, placement, maintenance requirement, and replication. More recently, the measurement of plant-water potential (directly or remotely) has been suggested as a method of scheduling irrigation (Geiser et al., 1982; Sojka et al., 1984).

Evaporation from containers such as National Weather Service Class A Evaporation Pans and washtubs has been used to either physically simulate a soil-water balance or to estimate potential ET for use in other water budget procedures (Westesen and Hanson, 1981; Doty et al., 1982). Covering these containers with screens not only reduced contamination and water loss caused by animals, but also reduced evaporation to a value nearly equal to potential ET (Campbell and Phene, 1976).

Various adaptations of the water balance technique have been developed, but are often restricted to specific crops, soils, or climatic regions and often require tedious recordkeeping or interpretation of charts and figures (Lambert, 1980; Doty et al., 1982; Gregory and Schottman, 1982). Inherent to these methods are the requirements to know soil-water retention characteristics, the degree of soil variation within the area being irrigated by a single system, measured or estimated daily ET, measured rainfall and irrigation amounts, initial soil-water storage, and, preferably, measured profile soil-water content during the growing season to correct the procedure.

For several years, computers have been widely used in arid regions to eliminate the tedious recordkeeping component of water balance methods and to estimate daily ET based upon daily meteorological inputs (Jensen et al., 1970; Kincaid and Heermann, 1974). Although efforts have been made to adapt this technology to the humid region and to incorporate rainfall predictions into

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the decision-making process, computer scheduling of irrigation is neither widely recommended nor practiced by irrigation managers (Rochester and Busch, 1972; Lambert, 1980). Difficulties in accurately assessing infiltration, runoff, and deep percolation losses for humid region soils and in estimating daily ET values are probably the primary reasons these methods have not been widely accepted. Computers have also been utilized in other scheduling methods which combine the water balance procedure with crop physiological models, rainfall predictions, and economic inputs in an attempt to provide the manager with the information necessary to make daily decisions regarding irrigation, particularly when resources are limited (Allen and Lambert, 1971a,b; Jones and Smajstrla, 1979; Hayes et al., 1983).

Development of water balance methods for programmable calculators (Kincaid and Heermann, 1974) and personal computers (Lambert, 1980) coupled with the increased availability of these machines provides a method of scheduling irrigation that offers the capability for a single computer to manage several irrigation systems for a wide range of soil, crop, and climate conditions. An additional benefit of computer-based methods is the capability to forecast seasonal water resource needs so that irrigation equipment may be matched to existing resources or additional water resources may be developed to satisfy irrigation needs.

The development and evaluation of several cultural and nutrient management practices have shown that corn yields of 14.5 Mg/ha are possible with irrigation in Coastal Plain soils (Rhoads, 1982). The objectives of our research were (a) to compare two irrigation scheduling methods, (b) to compare corn yields from these two irrigated treatments with yield from a nonirrigated treatment, and (c) to compare alternative cultural management concepts with those currently recommended for corn production in the region.

MATERIALS AND METHODS

This research was conducted over a three-year period (1980-82) on a Norfolk loamy fine sand (fine-loamy, siliceous, thermic Typic Paleudult). Selected soil characteristics and a profile description are included in Table 1. Three water management regimes, two row configurations, two plant populations, and two fertilization regimes were evaluated in a split-split-split plot design and were replicated four times. Water management treatments included a nonirrigated treatment (NI) and irrigation scheduled by two different methods. In 1980, tensiometers were used to manage irrigation on both irrigated treatments. Water was applied when soil water tension in the 30- to 60-cm depth range exceeded either 25 (TENS 25) or 50 kPa (TENS 50). In 1981 and 1982, water was either applied when the soil-water tension in this depth range exceeded 25 kPa or when indicated by a computer-based water balance (CBWB) (Lambert, 1980). Irrigation water was applied in increments of 10 to 25 mm which replenished the soil profile to levels no greater than 80% of maximum storage. This level was often exceeded, however, following rainfall.

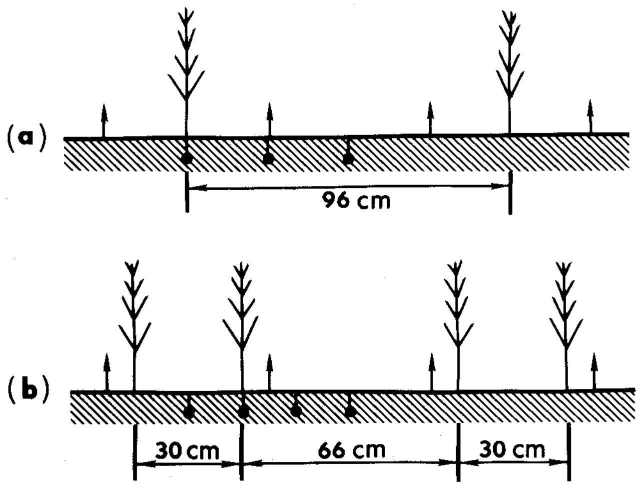

Fig. 1—Schematic diagram showing position of irrigation lines (vertical arrows), tensiometers (solid circles) and corn rows for (a) the single-row configuration and (b) the twin-row configuration.

The CBWB utilized daily maximum and minimum temperature, solar radiation, rooting depth, rainfall, and irrigation as inputs to calculate evapotranspiration (ET) and volumetric soil water content. Evapotranspiration was estimated using the Jensen-Haise equation (Jensen and Haise, 1963). A single soil-water retention relationship was used for all treatments. The CBWB was operated twice weekly in an effort to maintain volumetric soil water in the root zone between 50 and 80% of total available water. Daily rooting depth was estimated from periodic observations of root growth and experience. The maximum observed rooting depth was about 0.7 m which was approximately equal to the control zone in the tensiometer treatments. The rooting depth function was smoother in 1982 than in 1981 because of more frequent, but smaller changes which should be more representative of actual root growth. Each time the CBWB was operated, ET and soil-water content were calculated for the next five days using forecasts provided by the National Weather Service.

Irrigation water was applied through double-wall trickle irrigation tubing spaced 48 cm apart on the soil surface and with outlets spaced 30 cm apart along the line (Fig. 1). The system was operated at maximum design pressure (125 kPa) to provide a vertical stream of water which promoted uniform wetting. Water applied to each group of four plots was regulated with pressure regulators and measured with positive displacement

TABLE 1. DESCRIPTION AND SELECTED CHARACTERISTICS FOR NORFOLK lfs IN COASTAL PLAIN REGION NEAR FLORENCE, SC

Horizon	Depth, cm	Texture	Water available to plants, cm/cm	Bulk density, Mg/m^3	Water pH	CEC, cmol (p$^+$)
Ap	0-23	lfs	0.165	1.55	5.8	1.6
E	24-28	lfs	0.150	1.67	6.2	1.6
Btl	29-94	scl	0.196	1.54	4.7	2.4
Bt2	95-136	sc-scl	0.100	1.68	4.6	4.2
C	137-162	sl-scl	0.110	1.74	4.4	4.1

meters. Trickle tubing was replaced each year to prevent degraded irrigation uniformity caused by plugging or leaks.

The two row configurations were conventional single rows spaced 96 cm apart and twin rows which were spaced close enough to allow the use of conventional equipment, but allow improved plant distribution (Fig. 1). In 1980, twin rows were spaced 35 cm apart with each pair of rows spaced 112 cm apart. In 1981 and 1982 the twin rows were spaced 30 cm apart with each pair of rows spaced 96 cm apart.

The two plant population treatments were (a) equal to that currently recommended for commercial corn production (6.7 plants/m^2 in 1980, 7.1 plants/m^2 in 1981-82) and (b) a higher population similar to that reported as the maximum for intensively-managed corn in the region (8.9, 11.2, and 10.3 plants/m^2 for 1980, 1981, and 1982, respectively) (Rhoads and Stanley, 1978). Although significant interactions occurred among irrigation, plant population, and row configuration treatments in 1980 and 1981, mean yields for population treatments will be presented here. Detailed row configuration and plant population results are reported by Karlen and Camp (1984).

Pre-plant fertilization rates were uniform for all treatments with 65, 30, and 167 kg/ha N, P, and K, respectively, being applied in 1980 and 65, 30, 167, 53, 6.7, 3.4, and 2.8 kg/ha of N, P, K, S, Cu, Zn, and B, respectively, in 1981 and 1982. All supplemental nutrients were applied through the irrigation system for irrigated treatments and applied to the soil surface as a solution for the NI treatment. Supplemental N was applied in either two or four equal applications to give a total of either 200 or 315 kg/ha N in 1980. In 1981 and 1982, 135 kg/ha of supplemental N was applied to one fertilization treatment giving a total N of 200 kg/ha while the other treatment received supplemental N and K giving total applications of 336 and 280 kg/ha, respectively. In 1982, the high N treatment also received supplemental P to give a total nutrient application of 336, 43, and 280 kg/ha of N, P, and K, respectively.

Prior to planting, the experimental site was disked to incorporate plant residues and subsoiled in two directions (each diagonal to the row direction, but perpendicular to each other) at spacings of 96 cm and to a depth of 45 cm to reduce rooting restrictions caused by the E horizon. The site was disked again, and preplant fertilizer and herbicide were incorporated using a field cultivator or disk harrow. A mixture of butylate and atrazine was incorporated preplant for weed control. Turbufos (1980) or carbofuran (1981 and 1982) was applied at planting for insect control. A commercial corn hybrid (Pioneer 3382) was planted on 10 April 1980, 7 April 1981, and 2 April 1982, using John-Deere Flex-71* planters. The equipment was modified for planting the twin-row configuration by mounting two additional planter units on a standard two-row tool bar as close as possible to the existing units.

Tensiometers were installed at depths of 30, 60, 90, 120, and 150 cm at several positions relative to the row. Tensiometer positions relative to the row and trickle tubing for two row configurations are shown in Fig. 1. Mean values of all positions, row configurations, and plant populations at a given depth are used in this report. Tensiometers were serviced two or three times each week, and measurements were recorded three times each week. Rainfall was measured on site with a weighing-type recording rain gauge. The center 10 m^2 of each 34 m^2 twin-row plot and the center 12 m^2 of each 44 m^2 single-row plot were harvested, and grain yields were corrected to 15.5% moisture. Yield results were analyzed statistically using analysis of variance and Duncan's new multiple range test procedures (Steel and Torrie, 1980).

TABLE 2. WATER RECEIVED BY CORN FROM IRRIGATION AND RAINFALL DURING THE GROWING SEASON IN EACH OF THREE YEARS (1980-82)

Treatment	Water received 1980*	1981	1982
	----------mm----------		
TENS 25	448	252	155
TENS 50	284	—	—
CBWB	—	194	113
Rainfall	297	330	485

*Growing season is defined as day-of-the-year interval between planting and physiological maturity; 101 to 213, 97 to 209, and 92 to 210, respectively, for 1980, 1981, and 1982.

RESULTS AND DISCUSSION

Rainfall amounts during the growing season were 297, 330, and 485 mm, respectively, for 1980, 1981, and 1982 (Table 2). The growing season is defined as the day-of-year interval between planting and physiological maturity (101 to 213, 97 to 209, and 92 to 210 for 1980, 1981, and 1982, respectively). Annual irrigation amounts for each treatment and all years are also included in Table 2. The TENS 25 treatment received more irrigation water in each of the three years, but the amount applied each year was dependent on rainfall. The TENS 50 treatment (1980) and the CBWB treatment (1981 and 1982) each received 60 to 75% as much water from irrigation as the TENS 25 treatment.

In 1980 lengthy rain-free periods of 27 and 22 days occurred; the first occurred in the vegetative period, and the second occurred in the grainfill period. For the NI treatment, the major effects of these periods without rain were a significant reduction in plant height (Fig. 2) and a disruption of pollination timing. Seven rain-free periods of 5-8 days duration and one of 15 days duration occurred during the 1981 growing season. In 1982, one 11-day rain-free period occurred during grainfill, and two short rain-free periods of 5-6 days occurred during the vegetative period. There were no differences in plant height between the NI and irrigated treatments in 1981 or 1982 (Fig. 2).

Although soil-water tensions were measured at 30-cm intervals between the 30- and 120-cm depths, and the 30- to 60-cm depth zone was used for controlling the TENS-25 and TENS-50 treatments, soil-water tension data for the 30- and 90-cm depths only are reported. These data should accurately reflect soil-water conditions for most of the root zone since the maximum effective rooting depth for corn in these soils is approximately 1 m. Soil-water tensions at the 60-cm

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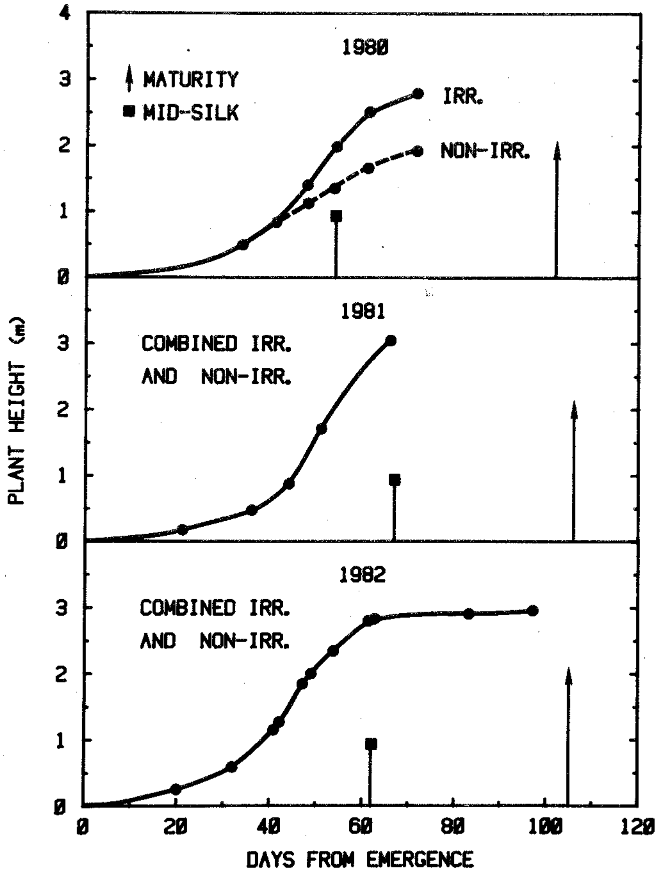

Fig. 2—Plant height as a function of time from emergence for each year (1980-82). There was no difference in plant height among water management treatments in 1981 and 1982.

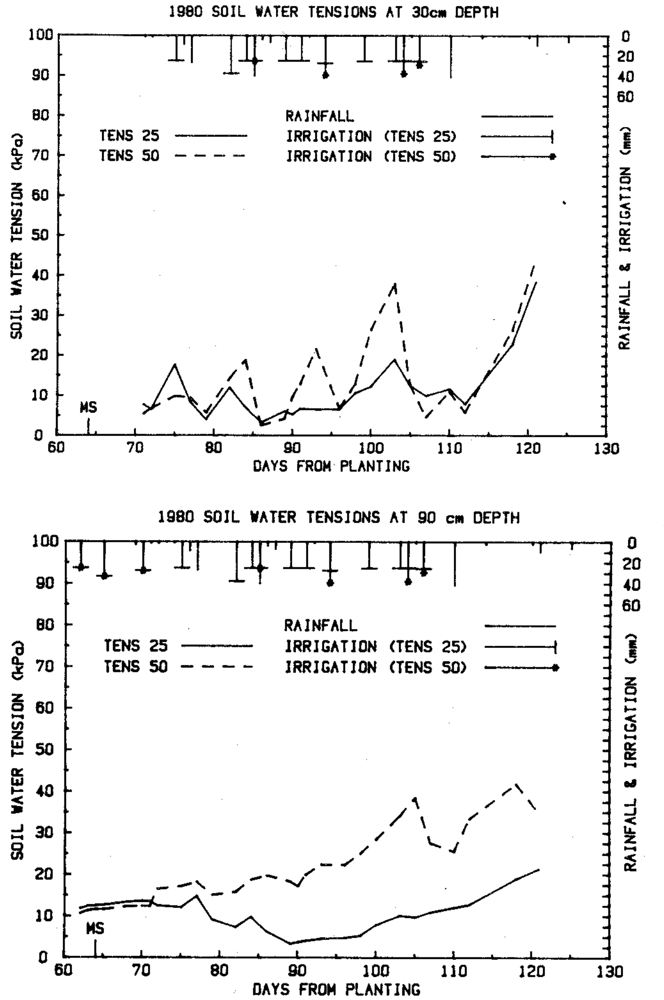

Fig. 3—Soil-water tension at the 30- (top) and 90-cm (bottom) depths for the two irrigation treatments during the 1980 growing season.

depth were generally intermediate between those at the 30- and 90-cm depths.

The soil was so dry in 1980 that soil-water tension at the 30- and 90-cm depths in the NI treatment were greater than 80 kPa (upper limit of tensiometer range) most of the time, and tensiometers could not be maintained in service. On the other hand, soil-water tensions for the TENS 25 and TENS 50 treatments were less than 20 and 40 kPa, respectively, for both the 30-and 90-cm depths (Fig. 3). In 1981 soil-water tensions at the 30- and 90-cm depths in the NI treatment again exceeded the tensiometer range much of the growing season. Soil-water tensions were less than 60 and 45 kPa at the 30-cm depth and less than 40 and 25 kPa at the 90-cm depth, respectively, for the CBWB and TENS 25 treatments (Fig. 4). Soil-water tensions remained below 85 and 70 kPa, respectively, at the 30- and 90-cm depths for the NI treatment in 1982. With three exceptions for the CBWB treatment (Fig. 5), soil-water tensions at these depths remained below 40 and 25 kPa in the CBWB and tensiometer treatments, respectively. Soil-water tensions in the CBWB treatment exceeded 40 kPa twice at the 30-cm depth and once at the 90-cm depth because of delayed reinitialization of the CBWB procedure using measured soil-water content.

The computed soil-water content in the root zone for the CBWB treatment in 1981 is included in Fig. 6. The stepwise increase in soil-water content between 0 and about 60 days after planting is caused by the increasing root depth. Ideally, the computed water content should remain within the region bounded by the freely-drained upper limit and allowable depletion curves. This was achieved except when irrigation was not provided as scheduled or when the computer program was reinitialized with measured soil-water contents which resulted in a rather large correction to the computed value. The discrepancy often appears more severe because reinitialization data is entered for the date soil samples were collected although the water content values were not calculated and available until several days later. After these data are entered into the CBWB program, calculated soil-water content for the days following reinitialization may be much different from the values which were used to make irrigation management decisions in real time. In 1981 the first reinitialization measurement occurred about 70 days after planting, but the soil-water content data were actually entered into the computer 14 days later. In this case, the new computed soil-water contents were lower (2 cm) than the previously computed values, and the CBWB indicated the need for irrigation at an earlier date (date of reinitialization). Although irrigation had occurred during this period, it was not sufficient to raise the soil-water content above the allowable depletion line until significant rainfall occurred about 85 days after planting.

In 1982 the first reinitialization occurred 60 days after planting, but was not entered into the program until 3 to 5 days later. Again, the CBWB procedure overestimated

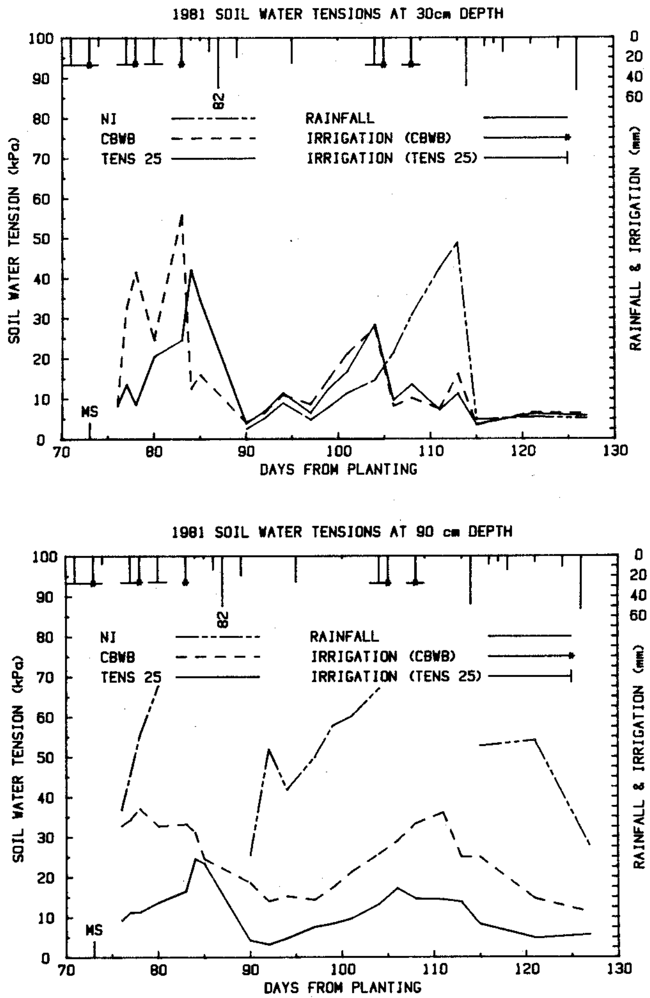

Fig. 4—Soil-water tension at the 30- (top) and 90-cm (bottom) depths for the NI and two irrigation treatments during the 1981 growing season. Numbers printed on daily rainfall lines reflect daily rainfall totals which exceeded the plotting range.

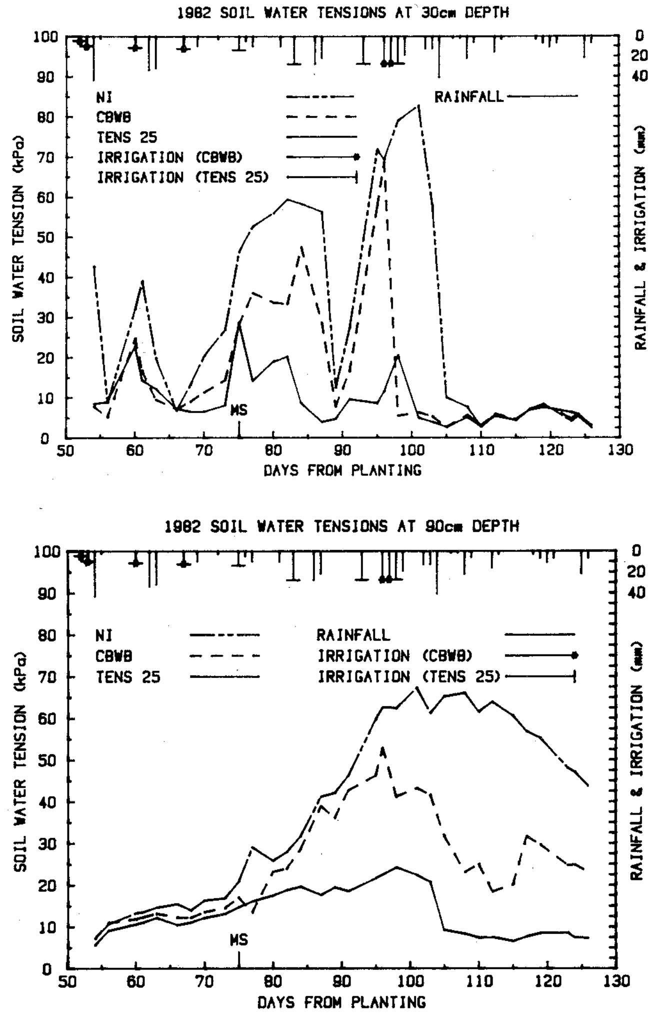

Fig. 5—Soil-water tension at the 30- (top) and 90-cm (bottom) depths for the NI and two irrigation treatments during the 1982 growing season.

(2 to 3 cm) the soil-water content of the profile, and the computed soil-water content curve dropped abruptly upon reinitialization. Fortunately, rainfall occurred during the period, and the soil-water content did not fall below the allowable depletion curve (Fig. 7). The second reintialization was performed about 90 days after planting when the soil profile was in a drying cycle. The CBWB procedure overestimated (2 to 3 cm) the soil-water content this time also, and the computed curve dropped abruptly after reinitialization. In this case, it dropped to a level significantly below the allowable depletion curve and indicates the possibility that moderately severe water stress in the corn may have occurred. Again, the reinitialization data were not entered into the program until 5 days after the soil

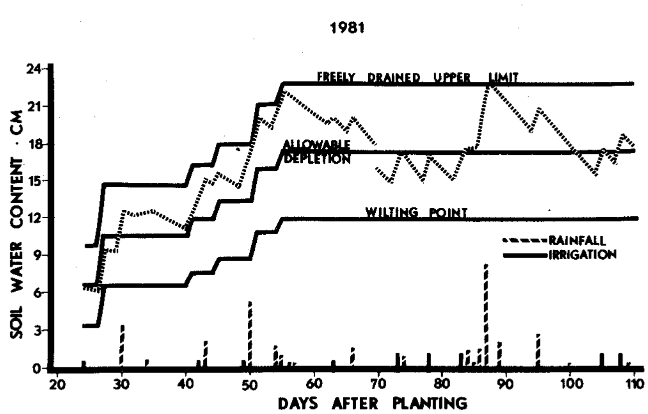

Fig. 6—Calculated soil-water content, irrigation, and rainfall for the CBWB treatment during the 1981 growing season. Wilting point is soil water retained at 1.5 MPa.

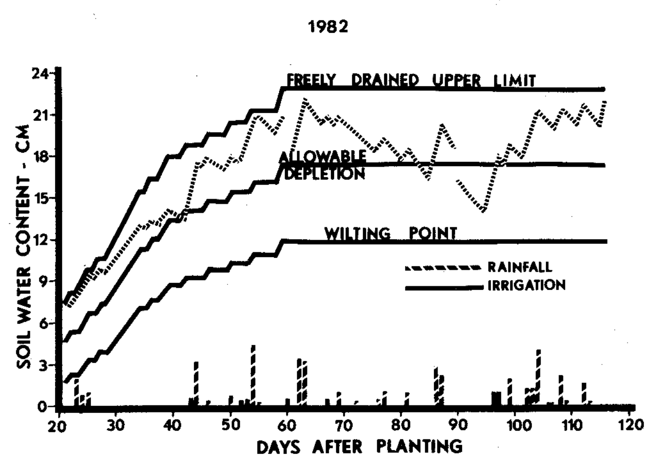

Fig. 7—Calculated soil-water content, irrigation, and rainfall for the CBWB treatment during the 1982 growing season. Wilting point is soil water retained at 1.5 MPa.

TABLE 3. COMPARISON OF POTENTIAL ET VALUES FOR A THREE-MONTH PERIOD (MAY-JULY) DURING THE GROWING SEASON IN 1981 AND 1982.

Method	1981	1982
	-----mm-----	
Jensen-Haise	505	522
Penman	460	479
FAO Penman	502	522
Thornthwaite	417	413
Blaney-Criddle	550	580
Pan evaporation	534	545

samples were collected. Problems of this type can be minimized through the development of a procedure to provide rapid soil-water content determinations and the timely entry of these data to the model.

The Jensen-Haise equation (Jensen and Haise, 1963) used to estimate ET from meteorological data in the CBWB procedure was used to estimate ET for three-month periods during the growing seasons in 1981 and 1982. These values were compared to total ET values estimated by other methods and to measured pan evaporation (Table 3). The Jensen-Haise estimates compare favorably with other estimates, particularly those using the Penman and FAO Penman equations. Pan evaporation was slightly higher than all but the Blaney-Criddle estimates; however, potential ET estimated from these pan measurements using the factor determined by Campbell and Phene (1976) (0.87 pan evaporation) was comparable with other ET estimates, particularly the Penman equation.

Mean corn grain yields were 11.11, 9.55, and 11.15 Mg/ha for the twin-row configuration and 10.34, 9.03, and 10.53 Mg/ha for the single row configuration, respectively, for the years 1980, 1981, and 1982 (Table 4). Significantly higher yields for the twin-row configuration may be a result of improved light interception and reduced intrarow competition. Interaction between water management and row configuration was not significant any year. Yields for row configuration treatments were not consistently different among irrigation methods. Corn grain yields for the twin-row configuration were higher for both irrigation scheduling treatments in 1980, for the NI treatment in 1981, and for the CBWB treatment in 1982.

Corn grain yields were significantly higher for the irrigated treatments in all years except 1982 when rainfall was almost adequate (Table 4). Water use efficiencies of the treatments were calculated on an irrigation basis [WUE(I)] by determining increase in crop yield above yield for NI treatment per unit of irrigation applied. WUE(I) values for the TENS 25 treatment were much lower in 1980 and 1981 (18 and 30 Mg/ha/m, respectively) than for the TENS 50 (28 Mg/ha/m) and CBWB (36 Mg/ha/m) treatments. All WUE(I) values were low in 1982 because of higher rainfall (6 to 7 Mg/ha/m). These values compare favorably with those reported by Hook et al. (1984) and Hammond et al. (1981).

There was no difference in yield between the two irrigation scheduling treatments each year although different amounts of irrigation water were applied. Irrigation resulted in grain yield increases of 8.05, 7.22, and 0.85 Mg/ha (150, 161, and 8%), respectively, for 1980, 1981, and 1982. The mean grain yield for all irrigated treatments declined 1.71 Mg/ha the second year of the study and declined an additional 0.58 Mg/ha the third year (Table 4). The reason for this decline is not known, but several possibilities exist. One possibility is that either air temperature, solar radiation, or both could have been significantly different among the three years of the study. Preliminary analysis of air temperature and solar radiation data in a corn growth model indicated that the variance in these data could not produce the measured yield differences. Other variables will be further analyzed in an effort to determine the reason for yield decline.

TABLE 4. CORN GRAIN YIELD FOR THREE WATER MANAGEMENT TREATMENTS AND TWO ROW CONFIGURATIONS IN EACH OF THREE YEARS (1980-82)

Irrigation treatment	Corn grain yield, Mg/ha					
	1980		1981		1982	
	Twin	Single	Twin	Single	Twin	Single
TENS 25	14.06a*	12.91b	12.14a	11.75ab	11.50a	10.95ab
TENS 50	14.00a	12.69b				
CBWB			11.70ab	11.22b	11.46a	10.58bc
NI	5.28c	5.43c	4.82c	4.13d	10.49bc	10.05c

*Number followed by the same letter within a year are not different by Duncan's multiple range test at P(0.05).

SUMMARY AND CONCLUSIONS

Results of this study confirm the feasibility of producing high corn grain yields in the Coastal Plain region of the southeastern U.S. provided water, nutrient, and cultural practices are carefully executed. The twin-row configuration treatment increased mean corn grain yields by 6% over the single-row configuration treatment. The irrigation scheduling methods provided different soil water regimes and required different amounts of irrigation water, but there was no significant difference in corn grain yield between irrigation scheduling methods within a crop year. From the yield standpoint, all scheduling techniques provided adequate irrigation management. The CBWB procedure (1981 and 1982) and the TENS 50 treatment (1980) required less irrigation water than the TENS 25 treatment. Water use efficiencies calculated on an irrigation basis [WUE(I)] were lower for the TENS 25 treatment than for the TENS 50 treatment (1980) and CBWB treatment (1981), but all WUE(I) were low in 1982 because of near adequate rainfall. The CBWB consistently overestimated available soil-water content both years, particularly during the pollination and grainfill growth stages when ET requirements were high. Delays in processing soil-water content data for reinitialization caused potentially damaging plant stress conditions. A technique for rapidly and inexpensively determining soil water content is needed to reduce this delay. Managers must also insure prompt entry of these data into the CBWB program and reinitialization of the scheduling program.

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